Understanding Pixel Defects in LCD Monitors

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Last revised: July 1, 2009

Introduction

Liquid crystal display (LCD) technology was first invented decades ago and has been improving ever since—to the point that today's high-quality flat panel displays deliver crisp, clear visual quality at a reasonable price. Even so, some LCD monitors may harbor tiny defects due to the extreme complexity of the manufacturing process. To deal with these inevitable minor flaws, HP has developed a set of policies and detection methods to help ensure that each customer receives the highest quality product available.

Executive summary

Flat panel LCD technology is a complex subject. To help you understand how pixel and sub-pixel defects occur, and what HP does about them, this white paper explains:

- **What are sub-pixels and how do they work?** A detailed look will show that millions of tiny sub-pixels cover the typical flat panel screen, producing the mixture of color and detail that forms the sharp, vibrant images flat panel users have come to expect.
- **How do pixel and sub-pixel defects occur?** The HP specification does not allow for any full or complete pixel defects. It does, however, allow for some minimal sub-pixel defects. This is because the current state-of-the-art in manufacturing processes still may produce a few sub-pixel defects per screen. These defects can be extremely hard to see unless they are viewed under special conditions, or unless they happen to be clustered in groups. Nevertheless, special practices and policies have been devised to reject any complete pixel defects and minimize sub-pixel defects.
- **What is HP doing about it?** HP has conducted a detailed study of its standards for sub-pixel defect specifications, and as a result, has adopted a more stringent unified standard for all models, which is discussed in greater detail later in this paper.
- **Why is this important to me?** Doing business with HP gives you the advantage of dealing with a company that strives to consistently deliver a higher standard of quality to its customers. In this case, no full or complete pixel defects, and fewer sub-pixel defects than most competitors. This means better quality for the customer and ultimately greater satisfaction for the end user because the user is viewing a cleaner image without the distraction of pixel defects.

Understanding TFT-LCD technology

Thin-film transistor (TFT) technology refers to a type of liquid crystal display (LCD), also known as an active-matrix LCD (AMLCD), used in all HP LCD monitors as well as HP iPAQ devices and HP notebook displays. To understand how pixel defects occur, it helps to understand the technology behind this type of LCD.

How LCDs work

A liquid crystal is exactly what it sounds like: a fluid substance which also exhibits some properties—such as an ordered arrangement of its molecules—similar to a solid crystal. In 1963, an RCA researcher discovered that liquid crystals can be used to control light, by switching a voltage across the material on and off. Before long, the technology was being applied to everything from calculators to computer monitors.

Because of their long, rod-like shape and electrical properties, liquid crystal molecules tend to line up in parallel rows in their natural state. When used in computer displays, this material is enclosed between two pieces of glass (in a flat panel display) and an image is generated by controlling the alignment of the LC molecules electrically, causing them to effectively act as "light valves"—letting light either pass through the panel or be blocked, depending on the voltage applied across the material. Color filters are placed on one side of the glass panels, with three different colors (red, green, and blue) for each pixel. Combining red, green, and blue light in different amounts, controlled by the voltage applied across the LC material at each of these individual areas (called subpixels) lets each pixel appear as any color and any brightness, and the combination of all the pixels on the panel creates the complete image.

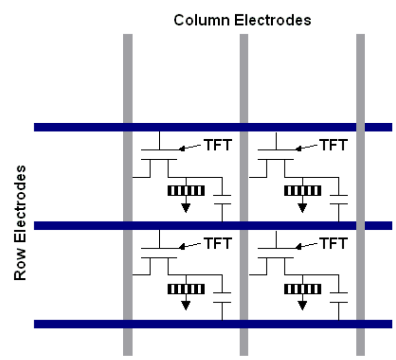
Fluorescent lights (very similar to the fluorescent tubes used in standard office lighting, but much smaller) or light-emitting diodes (LEDs) provide the "backlighting" for the LCD display—the light that will pass through the panel from the rear, and so create the image. The light from the backlight unit passes through a translucent plastic diffuser layer, which spreads the light evenly across the screen.

Why TFTs?

In the simplest LCD technology, the voltage applied across the LC material is delivered by transparent row and column electrodes, lines of conductive material which cross at 90 degrees (one set on the "top" glass, and the other on the bottom). The intersection of rows and columns define the pixels and subpixels of the display, and applying a voltage to a given row and column switches the pixel at that particular intersection. If the panel is driven such that the pixels are switched, in order across the display, very rapidly, the appearance of a complete image is produced. Unfortunately, when the drive voltage is removed from a given pixel and we move on to the next, that first pixel starts to switch back to its "off" state. This limits the contrast, resolution, and the response time that can be achieved with such a simple, passive-matrix drive system.

The advent of thin-film transistor (TFT) technology allowed transistors to be placed at each picture element or sub-pixel. These can switch very quickly, and then hold the state of the sub-pixel while the panel drivers take care of the other rows and columns of the display. This results in a great improvement in the contrast and response time possible with LCD technology, and permits the manufacture of large-size, high-resolution displays which rival any other display technology in performance.

Figure 1. How thin-film transistors are placed in the LCD array.



Understanding pixel defects

Active-matrix TFT-LCDs require at least one transistor to be created at each subpixel on the panel. This makes the average AMLCD an enormously complex device. For example, producing one of today's high-resolution WUXGA displays. with a 1920 x 1200 pixel native format requires embedding nearly seven million transistors in the screen (1920 x 1200 x 3 = 6.91 million). This is more than double the number of transistors found in the original Intel® Pentium® processor.

How pixel defects occur

Damage to any one of the millions of transistors within the LCD panel may leave a sub-pixel permanently on or off, creating a tiny dark spot or bright spot on the display. This is fairly common, even for small TFT displays on handheld computers.

Minute specks of dust on the panel, slight errors in the panel processing, and other problems encountered during manufacturing of the TFT array on the glass substrate cause these defects. When we look at the total number of pixels and subpixels on a 1920 x 1200 display, we see that the failure of one sub-pixel out of the 6.91 million is a very low failure rate indeed—only about 14 millionths of one percent (0.000014%). For lower-resolution SXGA displays, a single sub-pixel defect still represents a failure rate of only 25 millionths of one percent.

To look at it another way, having 10 sub-pixel defects on a 1280 x 1024 color panel means that the panel is still 99.9999% defect free!

How to spot a sub-pixel defect

Due to their tiny size relative to the screen, defective sub-pixels can be extremely hard to see. A defect in a sub-pixel is, visually, a single, tiny spot that is so small, it may be visible only if you display it against a background that specifically contrasts with the defective sub-pixel hue.

Because they appear brighter to the human eye, defective green sub-pixels may be easier to spot than defective red or blue ones. Sub-pixel defects are also easier to spot when they are clustered together in a single area. If all three sub-pixels in the same pixel fail simultaneously, you are more likely to detect the resulting light or dark pixel. However, since HP specifications require that TFT panels not have any complete pixel defects (i.e., all three sub-pixels defective), HP customers are not likely to encounter this situation.

To locate defective sub-pixels, the monitor should be viewed under normal operating conditions, in normal operating mode at a supported resolution and refresh rate, from a distance of approximately 20 inches (51 cm). The following standards show the typical conditions under which HP scans for pixel defects:

- Viewing distance of approximately 14 inches (36 cm)
- Ambient illumination of 300 to 500 lux (average room lighting can vary from 60 to 600 lux; typical museum lighting is 50 lux).
- Viewing angle of 70 to 110 degrees horizontal and 80 to 100 degrees vertical

HP pixel-defect standards

Since some degree of sub-pixel defects are inevitable, all manufacturers find it necessary to tolerate a minimal number of sub-pixel defects in their products. Replacing a panel with just a few minor sub-pixel defects is not recommended, since the replacement unit may also have a similar number of defects.

Historically, HP has maintained stringent manufacturing specifications for pixel defects, and it has been tightening those specifications over time.

HP specifications

HP pixel defect specifications continue to be refined, but will always represent the best panel quality standards which can reasonably be achieved, consistent with expected panel yields, the need to deliver products at competitive costs, and most importantly the goal of producing high-quality images on our displays. In a simplified format, the pixel defect specifications are as follows:

Table 1. This policy applies for HP monitors manufactured before May 2009:

Bright sub-pixel defects:	3 maximum
Dark sub-pixel defects:	5 maximum
Total sub-pixel defects:	5 maximum
Full pixel defects:	0 allowed

Table 2. This policy applies for HP monitors manufactured in May 2009 or later:

Bright sub-pixel defects:	2 maximum
Dark sub-pixel defects:	5 maximum
Total sub-pixel defects:	5 maximum
Full pixel defects:	0 allowed

Note: the date of manufacture is on the label on the back of the HP monitor.

As a result of these tight specifications, the majority of all HP monitors are shipping with no pixel defects at all (per HP's internal audits), and a small percentage with only a single sub-pixel defect. Most remaining units are shipping with only a few pixel defects that fall within the above listed range of acceptable pixel defects.

International standards (ISO-9241)

The International Standards Organization (ISO) has published its own set of specifications for pixel defects, contained within the ISO 9241 set of standards.. These identify three classes for measuring pixel defects in flat panel monitors:

- Class 0 panels are completely defect-free, including no full pixel or sub-pixel defects.
- Class 1 panels permit any or all of the following:
  - 1 full bright ("stuck on") pixel
  - 1 full dark ("stuck off") pixel
  - 2 single or double bright or dark sub-pixels
  - 3 to 5 "stuck on" or "stuck off" sub-pixels (depending on the number of each)
- Class 2 panels permit any or all of the following:
  - 2 full bright pixels
  - 2 full dark pixels
  - 5-10 single or double bright or dark sub-pixels (again, depending on the number of each; no more than 5 bright ("stuck on") subpixels are permitted).
- Class 3 panels permit any or all of the following:
  - 5 full bright pixels
  - 15 full dark pixels
  - 50 single or double sub-pixels stuck on or off

The HP specification ensures that all of our products exceed the ISO Class 2 requirements, as no full pixel defects are ever permitted; in most cases, HP displays will meet the more stringent Class 1 specification. As mentioned earlier, the HP specifications dictate no full pixel defects; further, we require no double sub-pixel

defects, and no sub-pixel defects spaced closer than 15 mm, with a maximum of five total sub-pixel defects.

Figure 2. Pixel fault definitions.

The pixel faults are defined in the following way:

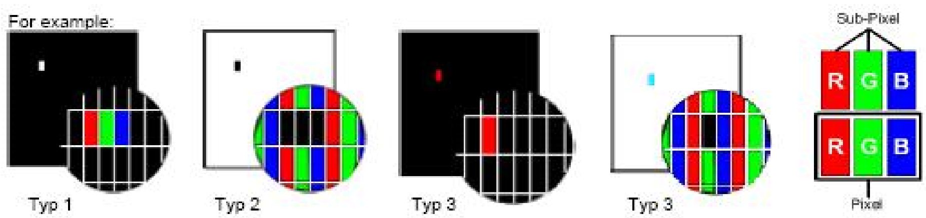
A pixel is a group of 3 assigned subpixels (red, green, blue). Each subpixel corresponds to a transistor.

Pixel fault Typ 1: constantly bright pixel

Pixel fault Typ 2: constantly dark pixel

Pixel fault Typ 3: defect subpixel, either constantly bright (red, green, blue or constantly dark)

For example:

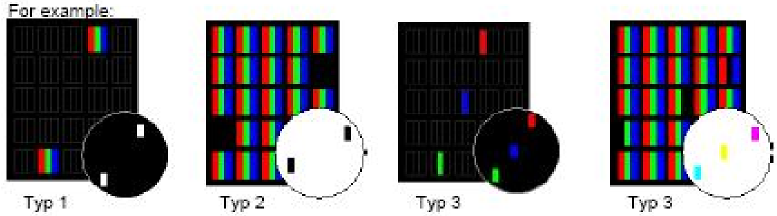


A cluster is an area of 5 x 5 pixel

Cluster pixel fault Typ 1 and Typ 2: constantly bright or dark pixels within the clusters

Cluster pixel fault Typ 3: defect subpixel, either constantly bright red, green, blue or constantly dark within the cluster.

For example:



Defect type definitions

Bright/dark dot: A sub-pixel stuck on or off.

Bright spots/lines: Spots or lines that appear light in the display. Defects do not vary in size or intensity (contrast) when contrast voltage is varied. Contrast variation can be achieved through the use of varying gray shade patterns. This defect may not completely block the light emitted by any pixels.

Cluster: A group of defective sub-pixels which are in close proximity to each other.

Cross lines off: When the unit lights, lines in both the minor and major axis do not appear.

Dark spots/lines: Spots or lines that appear dark in the display patterns and are usually the result of contamination. Defects do not vary in size or intensity (contrast) when contrast voltage is varied. Contrast variation can be achieved through the use of varying gray shade patterns. This defect may not completely block the light emitted by any pixels.

Dim line: When the unit lights, line(s) in the minor (vertical) or major (horizontal) axis appear dim, but not completely on or off.

Horizontal line: A line of pixels that crosses the display horizontally in portrait mode.

Mottling: When the unit lights, variation/non-uniformity (splotchiness) appears light (white) with the display and might vary in size.

Newton ring: A “rainbow” effect caused by non-uniform cell thickness.

Pixel: A picture element made up of three primary color sub-pixels (red, green, and blue), which combine to represent a single color dot on the display.

Polarizer dent: Physical damage to the polarizer that does not damage the glass. When the unit lights, spots appear light (white) with display patterns dark and do not vary in size. This defect may not completely block the light emitted by any pixels.

Polarizer scratch: Physical damage to the polarizer that does not damage the glass. When the unit lights, lines appear light (white) with display patterns dark and do not vary in size. This defect may not completely block the light emitted by any pixels.

Rubbing line/defects: Horizontal or diagonal lines that appear gray with the display patterns dark and may have resulted from an “out of control” rubbing process on the polyimide or “waves” on the BEFs or prism sheets.

Sub-pixel: A single point of light representing a primary color (red, green, or blue), which combines with the other two primary color sub-pixels to form a complete pixel.

Vertical line: A line of pixels that crosses the display vertically in portrait mode.

The HP advantage

The HP pixel defect specifications are part of HP's ongoing effort to provide high quality products. When it comes to LCD-TFT displays, fewer pixel defects mean better quality.

HP quality and reliability

HP prides itself on a reputation for industry-standard best-of-breed products—and our line of LCD monitors is a testament to that reputation. HP quality and reliability helps reduce maintenance, repair, and support costs throughout the monitor lifecycle and result in a high residual value for HP products. The HP strong market share reflects a global awareness and strong customer loyalty to the HP full line of innovative and competitively priced products. Here's how HP builds quality into every product.

- **Customer feedback**: HP products are a result of extensive customer feedback, including focus groups, trade shows, customer visits, support calls, human factors studies and surveys of thousands of desktop users.
- **Testing**: HP internal product teams help ensure reliability and long life by testing every model with hundreds of third-party devices in a variety of networked environments to simulate years of real-world stress. HP systematically pushes its products to make sure they will perform in the toughest workplace conditions.
- **Factory audits**: Before leaving the factory, each unit passes a rigorous examination to help minimize defects and increase likelihood of operation out of the box.
- **Engineering excellence**: HP quality does not stop at the factory door. Our service and engineering teams continue to support each unit throughout its lifecycle. The award-winning HP call center quickly resolves most issues on the first call.

Designed with the environment in mind

HP environmental policies are designed to help integrate sound environmental practices into every aspect of product design, including the following features:

- **EPEAT™:** The Electronic Product Environmental Assessment Tool (EPEAT) is a set of voluntary environmental performance criteria established by the IEEE 1680 American National Standard for the Environmental Assessment of Personal Computer Products that identifies 23 required and 28 optional criteria. Select HP business monitors are designated EPEAT Silver, indicating that they meet all of the required criteria and at least 14 of the optional criteria. The HP L1950g and HP L2245wg are designated EPEAT Gold, which indicates they meets all 23 required criteria plus at least 21 of the optional criteria.
- **Low emissions**: HP monitor products meet the demanding emissions, environmental, and ecological guidelines known as TCO 99 and TCO 03. TCO-approved products meet a number of strict new requirements set by TCO

Development, the world's leading organization for quality and environmental certification.

- **Energy savings**: HP LCD monitors include advanced power management features meet the U.S. Environmental Protection Agency's ENERGY STAR® requirements.
- **Recyclability**: Commonly recycled materials are easily identified, making it easier to find a market for discarded components.
- **Packaging**: Packaging consists of recyclable materials, no heavy metal inks, and minimal packaging material.
- **Disassembly**: Products are easily disassembled at the end of the product life to aid in recovery of recyclable components.
- **CFC-free**: Both HP and its suppliers use only CFC-free processes to protect the ozone layer from further damage.

HP service and support

HP LCD monitors are protected under the industry-leading HP support umbrella, which includes 65,000 sales and service professionals in 160 countries around the world who provide an impressive depth of service and support at the local level.

All HP LCD monitors come with a three-year limited global warranty on parts and labor, including the backlight. You can purchase a monitor in one country, move it to another country, and receive warranty service if the unit is still in warranty. In the United States, HP offers toll-free, round-the-clock telephone hotline support (terms and conditions may vary by region). Additional support is available 24 hours a day on the Web at www.hp.com.

HP Care Pack Services are also available. A part of the HP Total Care portfolio, these extended service contracts go beyond standard warranties and help maximize the initial return on investment and reduce the loss of productivity. For more details visit www.hp.com/hps/support.

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5981-6351EN July 2009